

ASAS Photometry of ROSAT Sources. I. Periodic Variable Stars Coincident with Bright Sources from the ROSAT All Sky Survey

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ABSTRACT

Photometric data from the ASAS – South (declination less than 29°) survey have been used for identification of bright stars located near the sources from the ROSAT All Sky Survey Bright Source Catalog (RBSC). In total 6028 stars brighter than 12.5 mag in *I*- or *V*-bands have been selected and analyzed for periodicity. Altogether 2302 variable stars have been found with periods ranging from 0.137 d to 193 d. Most of these stars have X-ray emission of coronal origin with a few cataclysmic binaries and early type stars with colliding winds. Whenever it was possible we collected data available in the literature to verify periods and to classify variable objects.

The catalog includes 1936 stars (1233 new) considered to be variable due to presence of spots (rotationally variable), 127 detached eclipsing binary stars (33 new), 124 contact binaries (11 new), 96 eclipsing stars with deformed components (19 new), 13 ellipsoidal variables (4 new), 5 miscellaneous variables and one pulsating RR Lyr type star (blended with an eclipsing binary). More than 70% of new variable stars have amplitudes smaller than 0.1 mag, but for ASAS 063656-0521.0 we have found the largest known amplitude of brightness variations due to the presence of spots (up to $\Delta V = 0.8$ mag). The table with the compiled data and figures with light curves can be downloaded from the *Acta Astronomica Archive*.

Key words: *Stars: variables: general – Stars: rotation – Stars: activity – X-rays: stars*

1. Introduction

The X-ray emission is related to high energy phenomena and its presence usually points to astrophysically interesting objects. The stellar coronae are the most ubiquitous X-ray sources in the solar neighborhood and their existence is related to the magnetic field generation *via* dynamo action below or within convective zones of cool stars (*e.g.*, Ossendrijver 2003, Brandenburg 2005, Browning 2008). The ROSAT all sky survey has unveiled a wealth of information about stellar activity in the solar surroundings (Voges *et al.* 1999). One of the most important parameters governing magnetic field generation is stellar rotation, which usually enters into studies of magnetic activity *via* the Rossby number: the ratio of rotation period to

the convective overturn time near the bottom of convective zone (Noyes *et al.* 1984, Stępień 1994, Pizzolato *et al.* 2003, Wright *et al.* 2011). To fully exploit ROSAT data in the study of activity *vs.* rotation period relation it is tempting to obtain as large as possible number of rotational periods of the ROSAT X-ray sources. Their photometric studies have been already subject of several papers (*e.g.*, Szczygieł *et al.* 2008, Norton *et al.* 2007), but complete survey of their photometric variability has not been done yet.

The number of stars known to be variable due to rotation of the spotted (nonuniform brightness) surface is growing quickly due to extensive photometric studies of star clusters and star formation regions.

Recently, Hartman *et al.* (2011) published an extensive study of rotational variability of K and M dwarfs based on the HATNet data for stars with declination between $+15^\circ$ and $+52^\circ$. Selection of stars was based on their colors and proper motions. The authors have found 2120 variable stars out of 27 560 stars analyzed for variability. Only 38 of these variable stars had been known before.

Fully convective M dwarf stars were the subject to the recent study by Irwin *et al.* (2011). The authors performed period search for 273 dwarfs and found 41 variable M-dwarfs. It is interesting that they found several stars with periods longer than 100 d, with the longest period equal to 154 d for LHS1667.

Our study is based on photometric data from the All Sky Automatic Survey (ASAS). A large catalog of about 50 000 variable stars, available *via* Internet has been described in several papers: Pojmański 2002, Pojmański 2003, Pojmański and Maciejewski 2004, Pojmański and Maciejewski 2005, Pojmański *et al.* 2005 (ASAS Catalog of Variable Stars: hereafter ACVS) but the data obtained by ASAS have not been fully explored yet. It is possible to select particularly interesting object or class of objects for subsequent study (for example study of β Cep variables: Pigulski 2005, or X-ray detected eclipsing binaries: Szczygieł *et al.* 2008), and also to find more variable stars not yet identified in the ASAS photometric database, as it has been shown in the search for β Cep stars (Pigulski and Pojmański 2008) or rotationally variable M dwarfs (Kiraga and Stępień 2007, hereafter KS2007).

In the present work we selected objects from the ROSAT Bright Source Catalog (Voges *et al.* 1999) to have a good statistics of their X-ray emission. Our primary goal was to obtain photometric periods for a large sample of coronally active stars in order to study period–activity relation. However, there are several classes of coronally active stars we would like to study separately: pre-main sequence stars (various subclasses of T Tau type stars), single main sequence stars, binary main sequence stars, evolved stars in binary systems (RS CVn type stars), single giants (FK Com type stars). In addition, coronally active stars are not the only X-ray emitters, therefore there is a necessity to classify variable objects: preliminary classification has been done on the basis of photometric and X-ray properties and the data found in the literature. In many cases catalogs of Strassmeier *et al.* (1993) or Eker *et al.* (2008) were particularly useful.

This paper includes information concerning star selection and analysis (Section 2), content of catalog (Section 3), overview of the data included in the catalog and presentation of particularly interesting variable stars (Section 4), summary and conclusions (Section 5).

The detailed period *vs.* X-ray activity relations for various carefully chosen samples of coronally active variable stars will be given in the forthcoming paper.

2. Star Selection and Analysis

We based our work on the data collected by the ASAS (south) cameras located at the Las Campanas, Chile. These observations, taken in *V*- and *I*-bands, covered declinations below $+29^\circ$. We analyzed the *I*-band data taken between March 25, 2002 and July 14, 2008, and the *V*-band data taken between November 20, 2000 and October 27, 2008, respectively.

The ROSAT All Sky Survey took place between July 30, 1990 and January 25, 1991 with some additional observations taken in February and August 1991 (Voges *et al.* 1999). Analysis of the data resulted in the detection of 145 060 sources with 18 811 sources classified as “bright” (ROSAT all-sky survey bright source catalog – RBSC, Voges *et al.* 1999). Bright source has a count rate more than 0.05 cts/s in the 0.1–2.4 keV energy band and has at least 15 photon counts.

There are 13 793 entries from the RBSC south of declination $+29^\circ$. The optical identification of the X-ray sources was based on coordinates given in the ROSAT catalog and the search in the ASAS photometric database was performed within $30''$ around a given position (roughly two ASAS pixels).

Several stars with large proper motions have not been identified in the ASAS photometric database due to change of position between ROSAT and ASAS epochs and have not been included in our present study. This is the case of four rotationally variable M dwarfs from KS2007: GJ 84, GJ 176, GJ 205 and GJ 551 (Proxima Centauri).

Good quality photometry is necessary for finding low amplitude variable stars. The lower envelope of standard deviations for ASAS photometric measurements is on the level of 0.01 mag for the *I*-band, 0.02 mag for the *V*-band and increases steeply for stars fainter than 11 mag, to reach 0.07 mag for a 12.5 mag stars in both bands. On the other hand stars brighter than 8 mag are saturated.

We performed period search only for stars with the following properties:

(i) the mean *I*- or *V*-band magnitude was between 8 and 12.5, (ii) for stars brighter than 8 mag dispersion was less than or equal to 0.1 mag, (iii) number of data points was not less than 40. These conditions are similar to those adopted by KS2007.

The initial period search was performed for 5851 sources in the *I*-band and 4207 sources in the *V*-band (altogether 6026 stars) using the AoV algorithm developed and described by Schwarzenberg-Czerny (1989). Because we limit our search to low amplitude variability resulting from spots, we decided to reject data points

deviating from the mean seasonal magnitude by more than 3.5 standard deviations, or by more than 0.35 mag. The average number of photometric measurements per star is about 225 for the *I*-band and 559 for the *V*-band.

Because many stars from our sample show long term variations, we have done period search separately for each season, unless the number of useful observations in the particular season was lower than 40 data points. A similar period search was also performed on the whole data set after subtracting season to season variations. For almost 3000 stars AoV statistics was larger than 10 (using 6 phase bins); these stars were further investigated using CLEAN algorithm (Roberts *et al.* 1987), and their photometric data were inspected visually. Finally we obtained a list of 2302 objects with detected variability.

2.1. Problems with Period Determination, Star Classification and Blending

Variability of stars due to spots may not be strictly periodic what introduces several problems. Formation of a new star-spot at the different longitude than the previous one may result in a new minimum and phase shift of the light curve. A new star-spot appearing at a different latitude on the differentially rotating stellar surface results also in different period of luminosity changes.

Objects monitored by ASAS are typically observed once per night or, sometimes, even more sparsely, depending on the weather conditions. The Nyquist frequency corresponds in this case to the period of 2 d. We looked for periods from 0.1 d up to 200 d. Because periods of fast rotating stars are shorter than the Nyquist limit, some obtained periods may be aliases of the true ones. This problem is particularly difficult for low amplitude variable stars with low signal to noise ratio. There are several examples that the period considered as the best based on the ASAS photometry (using AoV and CLEAN programs) is not correct but this can be checked only for the well known stars like FK Com, EZ Peg, MQ Lup, MS Ser, or variable stars found by surveys routinely observing the same field more frequently than ASAS. For this reason we decided to compare our results to the work of Norton *et al.* (2007, hereafter N07).

There are 428 variable stars found by SuperWASP project presented by N07. We performed period search for 162 of these stars, finding 76 of them to be variable. Forty object had periods similar to N07, 36 others had different periods mostly due to aliases. In most cases we considered periods given by N07 as more reliable than ours due to SuperWASP frequent sampling, so from our aliased periods we chose those corresponding to the periods given by N07. There were two cases where we had not adopted periods listed by N07. We classified ASAS 065948+2742.0 as a low amplitude contact binary with a period $P = 0.328532$ d, whereas the period given by N07 is 0.1965 d (alias to the half of our period). The star TYC 2064-1273-1 (ASAS 170313+2453.5) is a rotational variable with a period of 11.57 d. During the SuperWASP observations two groups of spots were present so the period given by N07 is 5.8417 d.

Uncertainties related to the presence of aliased periods for other stars motivated us to search for additional data present in the literature. We conducted the search mostly *via* SIMBAD database. As the most important data we considered projected equatorial velocity ($v \sin i$), lithium content and data on visual and spectroscopic companions.

Projected equatorial velocity together with a rotation period gives the minimum radius of a star. Probability of a given inclination between the rotation axis of a star and the observer's line of sight scales as $\sin i$, so it is more probable to see a star with a mildly inclined equator than almost pole on. Additionally, brightness variations due to rotation of spotted surface are more difficult to measure for stars observed almost pole on. Information about $v \sin i$ is usually sufficient to discriminate between aliases indicating slow or fast rotation (for example between aliased periods at $P = 1.11$ d and $P = 10$ d), however we cannot use this method to discriminate between aliases that are close in period domain (for example 2.22 d and 1.82 d).

There are numerous young stars on our list. These late type stars with significant lithium abundance are still contracting toward the zero age main sequence (ZAMS) and their dimensions may be significantly larger than stars of the same spectral type already on the main sequence (MS). This further limits the distinction between aliases based on the projected equatorial velocity. Lithium line equivalent width is an important indication of a stellar age. Lithium is also present in numerous giant stars on our list, but lithium equivalent widths for these evolved stars usually do not reach the level observed in very young stars.

For 520 stars (out of 2302) the periods are uncertain – most significant aliases were selected (see the Remark Section of the catalog).

Stellar classification is another important problem. When spots are stable, resulting variability may resemble low amplitude close eclipsing binary, ellipsoidal variability due to tidal deformation or pulsating star. Stellar pulsations with significant amplitude are confined to well defined regions in the Hertzsprung-Russell diagram, so using spectral types, or even colors is often sufficient to exclude pulsation as a source of variability. Distinction between close binaries and stars with stable star-spots is more difficult. If amplitude and shape of light curve change, spots are certainly present, but the presence of close companion star responsible for period stability is also possible. Spectroscopic observations should clarify ambiguity in classification of these stars.

In the case of detached binaries with large difference of surface brightness we may face problem with detection of the secondary minimum resulting in doubled period. There are several examples when a weak secondary minimum is present only in the *I*-band data and for the *V*-band data we observe only the main minimum.

Angular resolution of the ASAS cameras is similar to that of the ROSAT survey. There were many cases when angular resolution of $15''/\text{pixel}$ was not enough to uniquely identify variable object. We inspected visually Digitized Sky Survey

(DSS) images of variable stars to evaluate degree of blending. In the catalog we indicated stars with close neighbors found on DSS frames with a letter “B” (stars of comparable brightness so it is difficult to correctly identify the variable) or “b” (significantly fainter stars close to the suspected variable; there is a small probability that the fainter star was variable).

We also looked for close neighboring objects in available catalogs and other publications. In this way we obtained information about visual binary stars not resolved by DSS and about their separation and brightness difference. We decided to include information about blended variable stars together with the information about their known close neighbors. There are 1679 variable stars on our list without significant blending or known visual neighbors.

3. Content of the Catalog

The catalog includes information available in the SIMBAD database, ROSAT bright source catalog (Voges *et al.* 1999), ASAS photometric data, and some data taken from the literature.

Column 1 – ASAS designation equivalent to position from RBSC (hhmmss ± ddm.m).

Column 2 – a distance between the formal ASAS position and related object from SIMBAD database (arc sec), note – one pixel of ASAS detector = 14″.

Columns 3–12 include SIMBAD data (if present), the tilde “~” means no data available.

Columns 3–4 – object name (two columns).

Column 5 – object classification in the SIMBAD nomenclature.

Columns 6 and 7 – proper motion in right ascension, and declination [mas/year].

Column 8 – heliocentric parallax [mas].

Column 9 – radial velocity [km/s].

Column 10 – equivalent width of the lithium line at $\lambda=6704$ Å expressed in Å.

Column 11 – projected rotational velocity ($v \sin i$ [km/s]):

“a” – there are substantial differences in $v \sin i$ values found in literature,

“b” – data about $v \sin i$ are probably related to a companion star,

“<” – the upper, and “>” – the lower limit for $v \sin i$.

Column 12 visual companions (more information in remarks):

“-” – no known visual companion,

b – blended with much fainter star or stars,

B – blended with a star or stars of comparable brightness,

(b and B – information based on visual inspection of DSS frames – usually DSS-2-red),

c – close visual companion (visual binary) much fainter than the primary star,

C – close visual companion of comparable brightness,

(c and C – information based on SIMBAD database or literature - references in “remarks”).

Column 13 – close or spectroscopic companions (more information in “remarks”):

p – photometry may indicate a close companion,

P – definitely eclipsing binary (based on photometric data),

SB1, SB2 – spectroscopic binary (single lined and double lined, respectively),

SB3, SB4 – triple and quadruple spectroscopic systems,

? – there is no data about spectroscopic variability (no radial velocity measurement or single radial velocity measurement, no spectroscopic lines of secondary star) and there is no photometric indication of close companion,

no – radial velocity measurements indicate constant radial velocity (no close companion star detected),

C – composite spectrum of two or more stars, but without noticeable changes in the radial velocity.

Columns 14 and 15 – *B* and *V* magnitude (SIMBAD database).

Column 16 – spectral type. When no data available we put a tilde “~”, references to particular measurements not listed in the SIMBAD database are listed in remarks.

In the columns 17 – 22 we include the basic ASAS photometric data:

Column 17 – number of observations in the *I*-band,

Column 18 – mean magnitude in the *I*-band,

Column 19 – dispersion of the *I*-band measurements [mag],

Column 20 – number of observations in the *V*-band,

Column 21 – mean magnitude in the *V*-band,

Column 22 – dispersion of the *V*-band measurements [mag].

Column 23 – adopted bolometric correction for the *I*-band (BC_I), based on $(V - I)$ color (calculated from mean *I*- and *V*-band magnitudes) using a fit to atmospheric models presented by Bessel *et al.* (1998) in the form $BC_I = -0.08 + 1.86(V - I) - 1.33(V - I)^2 + 0.251(V - I)^3$ for values of $(V - I)$ in the range of (0–1.5), and a slightly changed formula given by Reid and Gilmore (1984) for values of $(V - I)$ in the range of (1.5–4.6): $BC_I = -0.31(V - I) + 1.03$. The value of the free parameter is changed from 1.05 to 1.03 to obtain continuity with the formula for smaller values of $(V - I)$. There are 5 stars without *V*-band measurements and 6 stars without *I*-band

measurements. We have not calculated bolometric corrections for these stars. Columns 24–27 include some observational data from RBSC:

Columns 24 and 25 – number of counts per second and its error,

Columns 26 and 27 – hardness ratio HRI , and its error ($HRI = (B - A)/(A + B)$), where A is a number of counts in energy band 0.1–0.4 keV, and B – a number of counts in energy band 0.5–2.0 keV).

Column 28 and 29 – logarithm (base 10) of the X-ray to the bolometric flux ratio and its minimal formal error (based only on uncertainties of the fit of the coronal model to X-ray observations). A conversion from the count ratio and HRI index to the flux in the 0.1–2.4 keV photon energy range is given by Schmitt *et al.* (1995): $F_x = (5.31HRI + 8.31) \cdot 10^{-12}$ cts. Here F_x is expressed in ergs/cm²/s and "cts" means counts per second listed in the ROSAT catalog. This formula was derived for X-ray coronal emission, but we adopted it for all stars. The value of R_x is calculated as F_x/F_{bol} where F_{bol} was obtained from mean I magnitude, bolometric correction BC_I , and the assumption that the solar absolute bolometric magnitude is equal to 4.75.

Column 30 – adopted period of luminosity changes.

Column 31 – lower limit for maximum amplitude of the I -band variability [mag].

Column 32 – lower limit for maximum amplitude of the V -band variability [mag]. Amplitudes of some variable stars (especially eclipsing variables) may be underestimated due to the rejection of extreme data points.

Column 33 – information about the photometric variability type:

ED – detached eclipsing binary,

EB – close eclipsing binary with deformed component, and unequal depths of eclipses,

EC – contact eclipsing binary,

Ell – variability due to the deformation of a star in a close binary system,

rot – rotational variability due to the presence of spots,

puls – variability due to stellar pulsations,

msc – the variability is difficult to interpret.

There are 1936 stars (likely 1236 new) listed as variable due to the presence of spots (rot). Our list also includes 127 detached eclipsing binary stars (33 new), 124 contact binaries (11 new), 96 eclipsing stars with deformed components (19 new), 13 ellipsoidal variable stars (4 new), 5 miscellaneous variables and one pulsating RR Lyr type star (blended with an eclipsing binary).

After column 33 we put our own remarks and data from the literature about particular objects. Information from different sources is separated by semicolons and may include:

P_ACVS – period from ASAS Catalog of Variable Stars,

Pphot – photometric period found in the literature (other sources then ACVS),
 n(vrad) – number of radial velocity measurements in cited paper,
 sig(vrad) – dispersion of radial velocity measurements given in cited paper,
 Porb – spectroscopic orbital period (with K1 and K2 radial velocity semi-amplitudes when available),
 RS – RS CVn type variable star – coronally active evolved star in a close binary system,
 RS? – probably RS CVn type star (based on photometric behavior and X-ray data), but its binarity should be confirmed,
 EW Li line – equivalent width of Li line at 6704 Å,
 vis bin – visual binary star with a given separation and luminosity contrast given by the difference in magnitudes at given band, or measured flux ratio at given band.
 F03 – star is listed in the catalog of Fuhrmeister and Schmitt (2003) and has variable X-ray emission

References to most often cited papers are written in the abbreviated form:

A12000 – Alcala *et al.* (2000), Bal87 – Balona (1987), Ber09 – Bernhard *et al.* (2009), Cov97 – Covino *et al.* (1997), CCDM – “Catalogue of the Components of Double and Multiple Stars” – Dommanget and Nys (2002), Cut99 – Cutispoto *et al.* (1999), daSil09 – da Silva *et al.* (2009), Guen07 – Guenther *et al.* (2007), Guil09 – Guillout *et al.* (2009), GCVS – “General Catalogue of Variable Stars” – Samus *et al.* (2009), KS2007 – Kiraga and Stępień (2007), KE2002 – Koen and Eyer (2002), LH98 – Li and Hu (1998), LEK87 – Lloyd Evans and Koen (1987), Nord04 – Nordstrom *et al.* (2004), N07 – Norton *et al.* (2007), R06 – Riaz *et al.* (2006), Str2000 – Strassmeier *et al.* (2000), T06 – Torres *et al.* (2006), WGH07 – White *et al.* (2007), W98 – Wichmann *et al.* (1998), W99 – Wichmann *et al.* (1999), W2000 – Wichmann *et al.* (2000), Zw2008 – Zwitter *et al.* (2008),

In the remarks we included also uncertainties about classification of the star (usually whether it is a low amplitude contact eclipsing binary or deformed binary star or rotationally variable spotted star), or its period (usually we listed the most significant aliases). Table 1 presents a sample of our catalog. Full version is available in the electronic form from the *Acta Astronomica Archive*¹. Files containing figures with photometric data and phased light curves of all variable stars (VAR_00_04.ps, VAR_04_05.ps, VAR_05_06.ps, VAR_06_07.ps, VAR_07_09.ps, VAR_09_12.ps, VAR_12_14.ps, VAR_14_16.ps, VAR_16_17.ps, VAR_17_18.ps, VAR_18_21.ps, VAR_21_24.ps) are also available for download from *Acta Astronomica Archive*. Stars are sorted by increasing right ascension, and the file VAR00_04.ps contains variables in right ascension range [0h, 4h). The first page of the file VAR_00_04.ps is presented in Fig. 1. References to the literature cited in the catalog are in the file “refs.dat”.

¹ftp://ftp.astrouw.edu.pl/acta/2012/kir_67

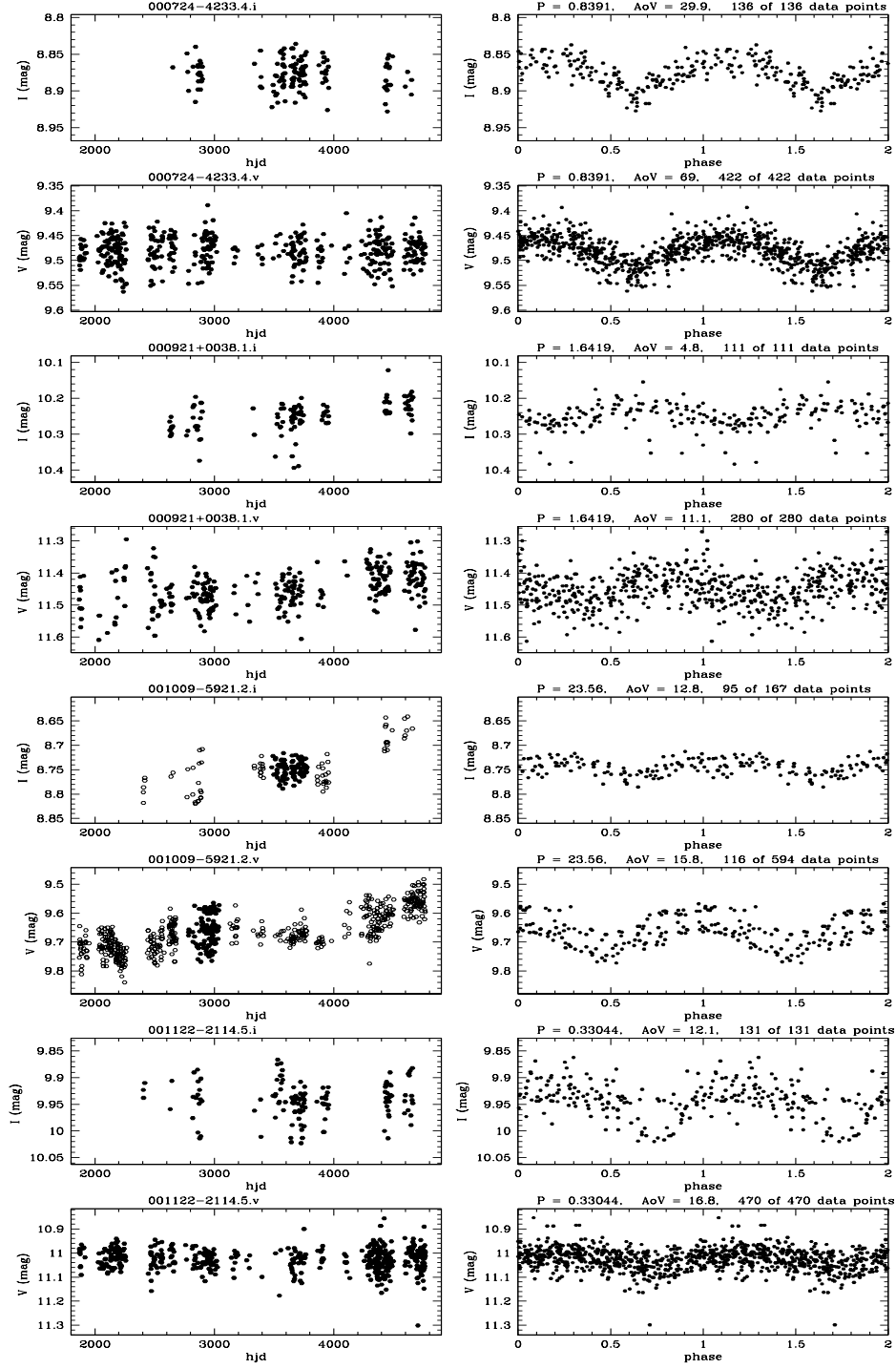


Fig. 1. Sample of stellar photometric data given as a function of $hjd = HJD - 2450000$ d, (*left panels*) and phased periodic variability (*right panels*). Figures for all stars are available in the electronic form from the *Acta Astronomica Archive* (ftp://ftp.astrouw.edu.pl/acta/2012/kir_67).

Table 1

The catalog of variable stars

col. 1	col. 2	col. 3	col. 4	col. 5	col. 6	col. 7	col. 8
ASAS des	sep	object	name	SIMBAD type	μ_α	μ_δ	plx
000724-4233.4	12.55	HD	271	*	-14.80	-4.00	~
000921+0038.1	11.86	TYC	1-1187-1	pr*	119.40	-29.70	~
001009-5921.2	15.97	CD-60	8	*i*	15.40	6.10	~
col. 9	col. 10	col. 11	col. 12	col. 13	col. 14	col. 15	col. 16
v_{rad}	Li EW	$v \sin i$	blend	sp. comp.	B	V	sp. type
-56.4	~	~	-	p	9.97	9.55	F5/F6V
-20	0.10	28.1	-	SB2	12.20	11.88	K4Ve
-10	0.11	18.0	B	SB2	10.78	9.92	G8III
col. 17	col. 18	col. 19	col. 20	col. 21	col. 22	col. 23	col. 24
n(I)	$\langle I \rangle$	$\sigma(I)$	n(V)	$\langle V \rangle$	$\sigma(V)$	BC(I)	cts
138	8.881	0.034	424	9.482	0.034	0.61	0.087
111	10.252	0.043	281	11.452	0.060	0.67	0.114
167	8.747	0.033	596	9.664	0.069	0.70	0.163
col. 25	col. 26	col. 27	col. 28	col. 29	col. 30	col. 31	col. 32
e(cts)	$HR I$	e(HR1)	$\log(R_x)$	e($\log(R_x)$)	P	amp(I)	amp(V)
0.025	0.10	0.29	-3.71	0.46	0.8391	0.052	0.061
0.019	-0.01	0.16	-3.05	0.27	1.6419	0.060	0.069
0.036	0.78	0.18	-3.31	0.30	23.56	0.033	0.102
col. 33							
type	Remarks						
rot	also possible Ell or EB and $P = 1.6782$ d; n(vrad)=1 (Zw2008)						
rot	SB2, $v \sin i = 28.1$ km/s, n(vrad)=1, EW Li line = 0.1 A (T06); P_ACVS 0.621853;						
rot	RS; SB2, dV=2.5, $v \sin i = 18$ km/s, n(vrad)=1, EW Li line = 0.11 A (T06);						

4. The Overview of the Catalog Content

Our catalog contains 2302 variable stars. The discussion of statistical properties of the sample and a presentation of interesting objects is given below.

4.1. The V and I magnitude and $(V - I)$ color distribution

Histogram illustrating the number of stars in 0.5 mag bins is presented in the left panel of Fig. 2 (I -band – the dotted line, V -band – the solid line) and has maximum around $I = 9.5$ mag and $V = 10.5$ mag. There are variable stars down to the $V = 14.5$ mag, but they have been found to be variable using only I -band data. As we expect for population of stars thought to be dominated by coronal sources the most of variable stars have $(V - I)$ color typical for stars with outer convection zones (see the right panel of Fig. 2). The maximum around $(V - I) = 1.0$ mag in-

indicates that K-type stars are most numerous in our sample. There are six stars with $(V - I) > 3$ mag, with $(V - I) = 3.46$ mag for the reddest one (ASAS designation 173353+1655.2). A few stars with the bluest colors $(V - I) < 0.3$ mag are not expected to be coronal sources. In this color range we expect main sequence stars of early spectral type (not later than A3) and cataclysmic binaries. This is confirmed by spectral classification found in the SIMBAD database.

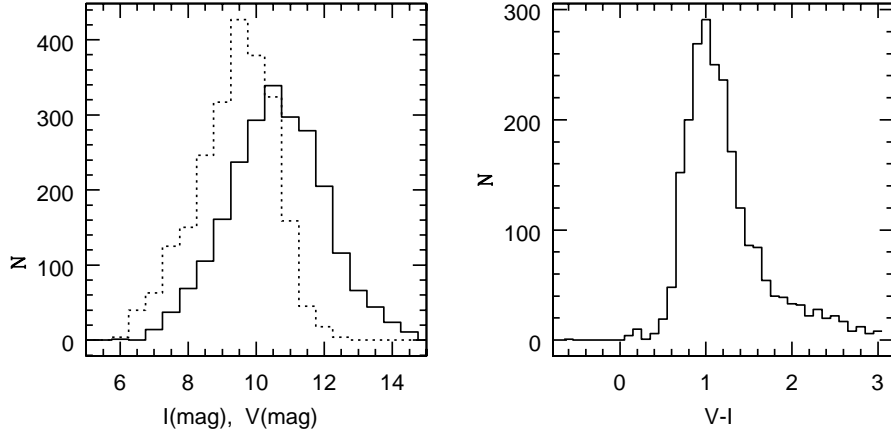


Fig. 2. Basic photometric properties of 2302 periodic variable stars illustrated in histograms. *Left panel:* number of stars in 0.5 mag bins: *I*-band sources – dotted line, *V*-band sources – solid line. *Right panel:* number of stars as a function of $V - I$ color (0.1 mag bin in $V - I$).

Some stars close to the Galactic plane or star formation regions may be subject to significant absorption and reddening. *E.g.*, NGC 3603 A1 (Moffat *et al.* 2004) and HT Lup (Prato *et al.* 2003) have total absorption of 4 mag in the *V*-band. For most of the stars we have no data about their reddening and we could use maps of total Galactic extinction (Schlegel *et al.* 1998) as an indication of maximum extinction in a given direction.

We do not have $(V - I)$ color data for 10 stars, of which 5 stars are without *V*-band measurements and 6 stars are without *I*-band measurements.

4.2. Spectral Classification

Spectral types, taken mainly from the SIMBAD database, are given for 1699 stars and are summarized in Table 2 (7 stars with luminosity class IV/III are included in the III luminosity class, and 10 stars IV/V are in the IV luminosity class). There are also known 11 white dwarfs related with stars listed in the present catalog, six are components of cataclysmic binaries (BL Psc, IX Vel, DH Leo, BV Cen, AE Aqr, and most likely V341 Ara), and five are close neighbors of variable stars. Probably there is also a neutron star present in the X-ray symbiotic star IGR J16194-2810.

Most stars have spectroscopic classification typical for the coronally active stars. For early type O and B stars we expect X-ray emission from binary stars as a result of colliding winds, or interactions in close systems.

Table 2

Spectral classification of the primary stars listed in the catalog

spectral type luminosity class	O	B	A	F	G	K	M	tot
II	0	0	0	0	0	2	0	2
III	0	0	0	3	84	138	4	229
IV	0	0	3	10	81	90	1	185
V	1	1	5	67	225	353	82	734
not given	2	3	15	44	175	235	75	549
total	3	4	23	124	565	818	162	1699

Among three O-type stars there are two eclipsing binaries, NGC3603 A1 (111510-6115.6) and MY Ser (181806-1214.6), and one cataclysmic variable, V341 Ara.

Among four B-type stars, two, HD 79905 (091407-6032.0) and HD 195134 (202908+1241.0), are small amplitude ($dV \approx 0.05$ mag) eclipsing or ellipsoidal variable stars, one, LM Lup, is a rotationally variable, chemically peculiar α CVn type star, and one, IX Vel (081519-4913.2), is a cataclysmic variable star.

There are only two stars of luminosity class II in our catalog: MQ Vir (135952-2220.8), described later, and CD-46 10694 (162335-4631.7) with a period of 44.7 d. The latter star is a fast rotating giant with a projected equatorial velocity equal to 35 km/s (T06). Assumption that variability period is equal to the rotation period gives the minimal radius of the star 30 times larger than the solar radius. This requires the presence of a companion to tidally spin up the giant star to a present rotation rate.

Late type giants are known not to be coronally active (Güdel 2004). This is also apparent in our study where we find four stars classified as M-type giants but only for two of them X-ray emission may be directly related to the giant star itself.

The star GSC 06806-00016 (IGR J16194-2810, ASAS 161933-2807.5) is classified as a symbiotic X-ray binary and its X-ray emission is related to the compact companion. The M2III star HD 184189 is blended with a fainter companion ($\Delta V = 1$ mag) so eclipses with a period of $P = 2.1334$ d (and most probably X-ray emission too) are not related to the red giant star. The M0IIIe type star ASAS 092505-4327.8, is very unusual with the high amplitude variability (up to 0.5 mag in the V-band), fast rotation ($v \sin i = 35$ km/s) and the high activity ($\log(R_x) = -2.6$). Most probably it is a very young star still contracting toward the main sequence ($R_{\min} = 7 R_{\odot}$) rather than the evolved one.

The only variable M type giant with X-ray emission and a firm spectroscopic classification is KP Aqr (unresolved Hipparcos variable). We adopted 21.8 d as variability period for this star, but other periods were also detected. The rotational

variability cannot be reconciled with star's parameters. The recent parallax calculation for KP Aqr, based on Hipparcos data (van Leeuwen 2007), gives a distance of about 400 pc, so its bolometric luminosity is about $400 L_{\odot}$ and its radius is more than $40 R_{\odot}$. Rotation with a period equal to 22 d would be faster than the breakup rotation for a solar mass star with $R = 40 R_{\odot}$. The variability may be related to small amplitude pulsations (like OGLE Small Amplitude Red Giant stars, Soszyński *et al.* 2011), but this suggestion needs to be confirmed.

Small number of M giants in our sample indicates that most of M-type stars with not given luminosity class are dwarfs.

4.3. Period Distribution

We limited our search to the periods between 0.1 d and 200 d. Periods range from 0.1371 d (for the ASAS 102045-6311.3) up to 192.8 d (IGR J16194-2810=ASAS 161933-2807.5). Their distribution presented in Fig. 3 has maximum around 3 d. Most stars (95.5%) have periods between 0.29 d and 50 d. There are five stars in our catalog with the periods above 100 d: 083531-0904.1 ($P = 171.2$ d), NV Hya (091701-0937.1, $P = 145$ d), MQ Vir (135952-2220.8, $P = 120.4$ d), GSC 06806-00016 (161933-2807.5, optical counterpart to the gamma ray source IGR J16194-2810, $P = 192.8$ d), and HD 341626 (180816+2350.5, $P = 123.4$ d). For those stars photometric observations and phased light curves are presented in Fig. 4. Three of them, already known to be variable (NV Hya – Perryman *et al.* 1997, MQ Vir – Koen and Eyer 2002, HD 341626 – ACVS), are K0-type giants ($1.1 < (V - I) < 1.3$), characterized by rather hard X-ray emission ($HRI = 0.73-1.0$) and quite high activity ($\log(R_x) \approx -4$). Most probably, they are active coronal sources. None of these stars is confirmed to be a spectroscopic binary, but they are candidates for RS CVn type stars due to their spectral types, character of photometric variability and the high X-ray activity. The star, ASAS 083531-0904.1, is an optical counterpart to the X-ray source 1RXS J083531.6-090409. Its variability period is close to 170 d, but there are also possible aliases close to 1 d or 0.5 d. According to Schlegel *et al.* (1998) Galactic extinction in the direction of this star is moderate ($A_V = 0.144$ mag) so reddening is not significant. The red color of the star ($V - I = 1.9$ mag) and relatively high activity ($\log(R_x) = -3.4$) may indicate that it is a red dwarf, or that its X-ray emission is of non coronal origin.

GSC 06806-00016 (ASAS 161933-2807.5) is an optical counterpart to the gamma and X-ray source (IGR J16194-2810) classified as a symbiotic X-ray binary (Masetti *et al.* 2007). The X-ray source coincides with the red giant of spectral type M2III but very red color ($V - I = 2.75$ mag), results most probably from the interstellar reddening ($A_V = 3.2$ mag in the direction to the star, Schlegel *et al.* 1998). We detected *I*-band photometric variability with an amplitude of 0.11 mag and a period of 192.8 d what we interpret as a result of ellipsoidal distortion due to the presence of a massive companion. However, the pulsation with the period two times shorter is also possible. The object is very active ($\log(R_x) = -2.94$) and has

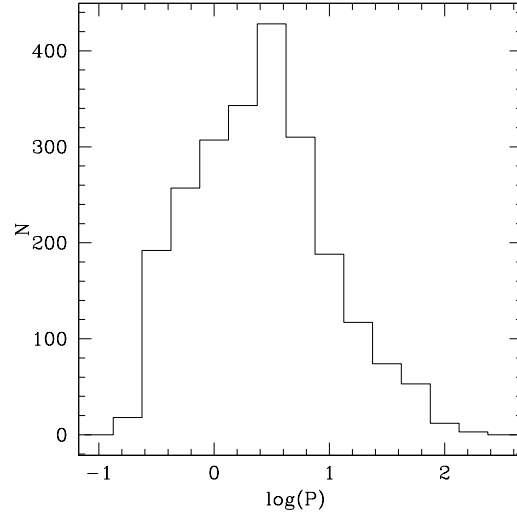


Fig. 3. Histogram of variability periods. Number of stars in $\log(P)$ bins equal to 0.25 (period is expressed in days) is given.

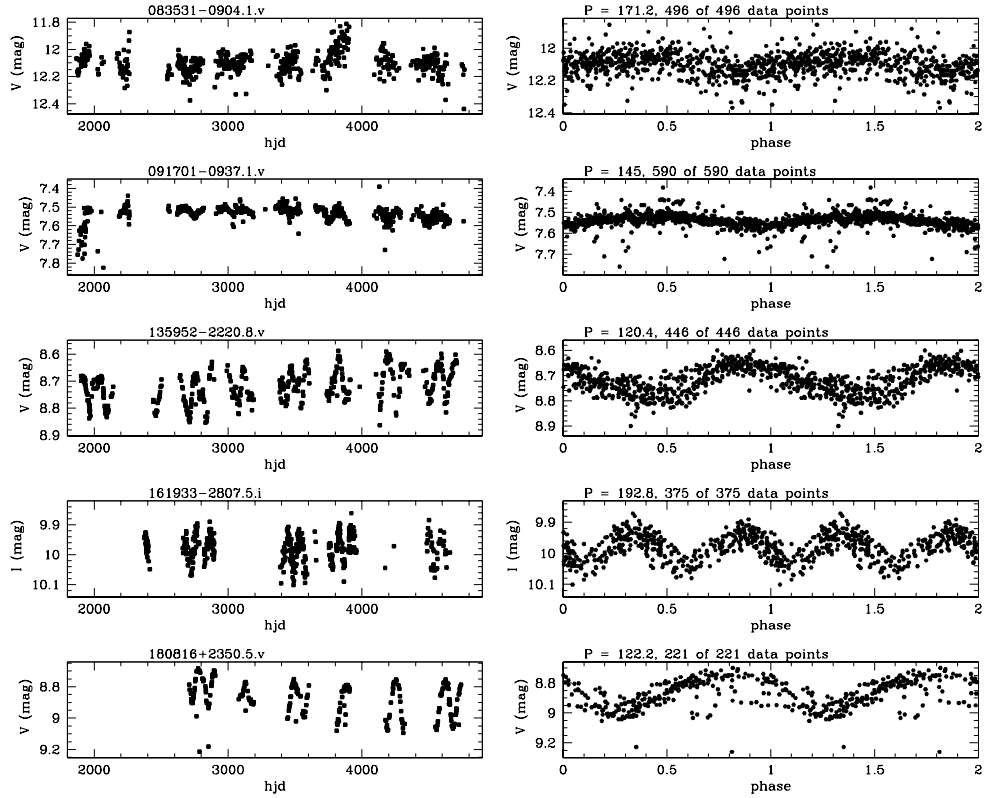


Fig. 4. Stars with the longest variability periods. *Left panels:* photometric data as a function of $\text{hjd} = \text{HJD} - 2450000$ d. *Right panels:* photometric data points phased with the adopted variability period.

been detected also above 30 keV by INTEGRAL (its ROSAT *HRI* “color” is equal to 0.96). The star is a LMXB with the compact object (neutron star or black hole) and the giant star companion.

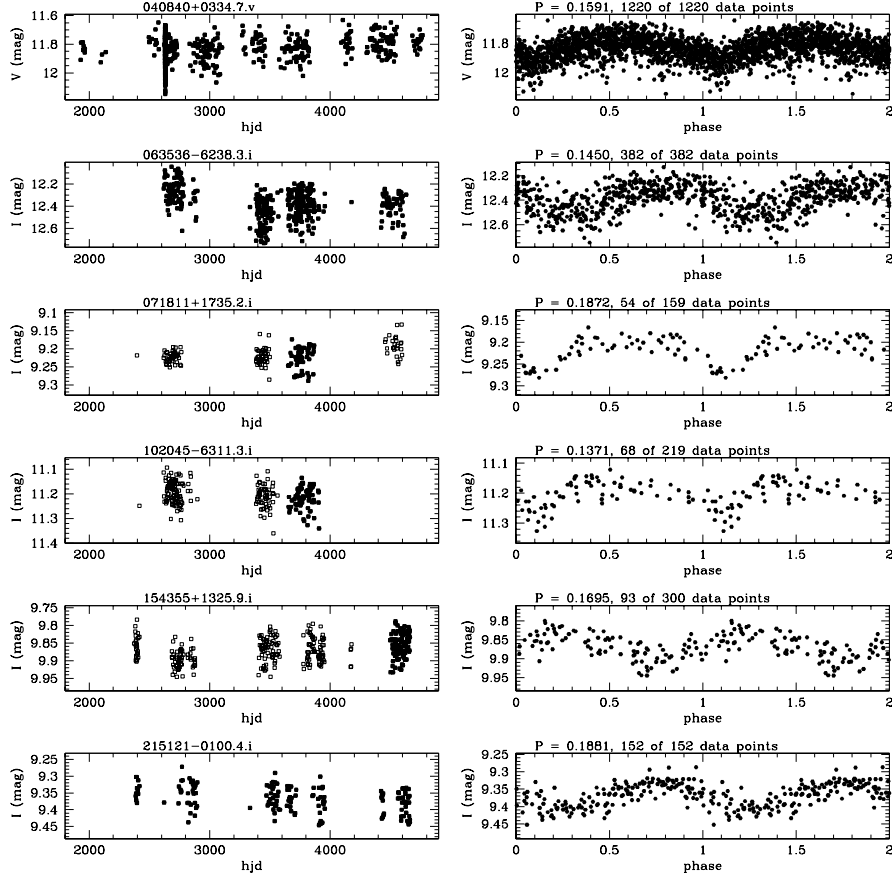


Fig. 5. Stars with the shortest variability periods. *Left panels*: photometric data as a function of $\text{hjd} = \text{HJD} - 2450000$ d. *Right panels*: photometric data phased with the adopted variability period.

Stars with rotation periods shorter than 0.2 d are usually considered as a very fast rotators. They are tracers of the apparent decline in activity called supersaturation (Prosser *et al.* 1996). There are six stars with periods shorter than 0.2 d in our sample. One of the stars is RR Pic (Nova Pic 1925, ASAS 063536-6238.3), well known cataclysmic variable star which erupted as a slow nova in 1925. The orbital period of $P = 0.1450255$ d was determined by Vogt (1975). The star has a blue color ($I = 12.39$ mag, $V = 12.50$ mag) and its X-ray emission is most probably of non coronal origin. Other stars with periods shorter than 0.2 d are probably coronal sources of spectral type K (ASAS 071811+1735.2, 154355+1325.9, 215121-0100.4) and M (ASAS 040840+0334.7, 102045-6311.3). Two of these

stars are known to be variable (ASAS 154355+1325.9 with $P = 0.16952$ d, ASAS 215121-0100.4 with $P = 0.18816$ d, ACVS) and our periods are essentially the same. Photometric observations and phased light curves of six stars with shortest periods in our sample are presented in Fig. 5.

ASAS 102045-6311.3 corresponds to the X-ray source 1RXS J102045.8-631121 and has the shortest period ($P = 0.1371$ d) on our list. The identification of the variable star is not certain because of blending. The brighter star is red, $(V - I) = 2.2$ mag, and has spectral type M4 (Riaz *et al.* 2006). Its very high activity ($\log(R_x) = -2.4$ and $HRI = 0$) may confirm that for very late type dwarfs super-saturation is not observed (Jeffries *et al.* 2011).

4.4. Variability Amplitude of Spotted Stars

The largest amplitude of variability related to the presence of star-spots has been observed for stars above the main sequence. The best known examples are the pre-main sequence star V410 Tau with ΔV up to 0.65 mag (Strassmeier *et al.* 1997) and the evolved (spectral type K0III) RS CVn type star XX Tri with ΔV up to 0.63 mag (Strassmeier 1999, Strassmeier 2009).

Most of the rotationally variable stars found in our study have small amplitudes as can be seen in the histogram presented in Fig. 6. More than 70% of the newly detected variable stars have the amplitudes smaller than 0.1 mag and only 47 among them have the amplitudes larger than 0.2 mag.

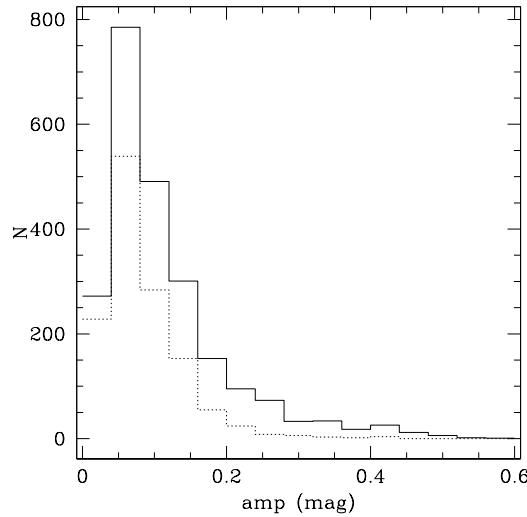


Fig. 6. Histogram of maximum variability amplitude of variable stars. Number of stars in bins of variability amplitude is equal to 0.04 mag. All periodic variable stars – solid line, new periodic variable stars – dotted line.

One of the new variables, ASAS 063656-0521.0, presents particularly large luminosity changes due to presence of star-spots. It is an optical counterpart to the X-ray source 1RXS J063656.7-052104. We classified this star as a rotational vari-

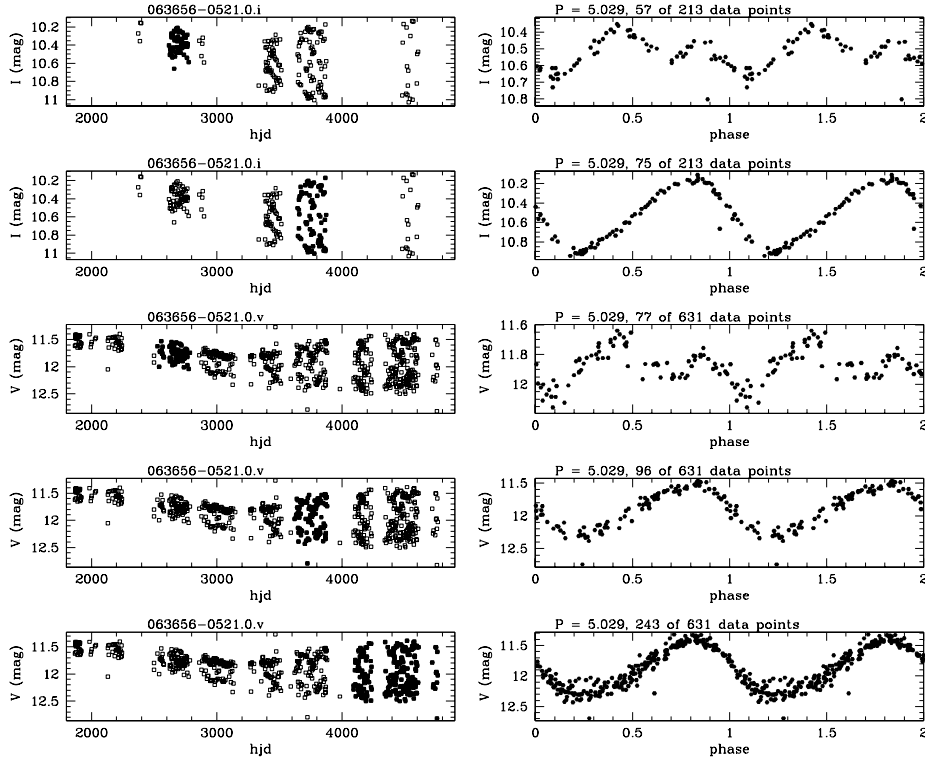


Fig. 7. ASAS 063656-0521.0 photometric data (*left panels*) and the phased light curve (*right panels*). The *I*-band light curve is given for two different seasons (*two upper rows*) and *V*-band light curve is given for three different seasons (*three lower rows*).

able with a highest seasonal brightness variability (up to $\Delta V = 0.8$ mag). This star showed significant activity changes. Its mean *V* dropped from 11.5 mag to 12.0 mag between $\text{hjd} = 1880$ and $\text{hjd} = 4200$ (with $V - I$ color changing from 1.26 mag to 1.38 mag). At the same time variability amplitude changed from $\Delta V = 0.2$ mag to $\Delta V = 0.8$ mag. The shape of the phased light curve also changed (see Fig. 7). Star's rotational period is equal to 5.029 d and it is constant throughout all observational seasons what may suggest the presence of a close companion star. The star is very active ($\log(R_x) = -2.7$) and its X-ray emission is hard ($HRI = 0.80$). We consider this star as a RS CVn type star candidate. Photometric measurements and a phased light curves for seasons of modest and largest brightness variations are presented in Fig. 7.

Rotationally variable stars with large photometric variability are sometimes misidentified with pulsating stars or eclipsing variables. There are two stars in ACVS with maximum amplitudes of luminosity changes above $\Delta V = 0.5$ mag and properties very similar to the ASAS 063656-0521.0. They are: CD-58 693 (ASAS 032738-5809.5), identified as a Cepheid with the period of $P = 4.075$ d, and ASAS 131055-4844.0, classified as a probable spotted contact binary with two most significant periods $P_1 = 7.06562$ d and $P_2 = 3.537421$ d (Pilecki and Szczygieł

2007). They are likely very active ($\log(R_X) \approx -2.8$) RS CVn type stars, but their binarity has to be confirmed.

4.5. *Eclipsing Binaries, Ellipsoidal Variable Stars and Spectroscopic Binaries*

There are 127 detached eclipsing stars in our list (33 new), 98 binaries with deformed components but unequal minimum depths (19 new) and 124 contact binaries (11 new).

There are some early type eclipsing binaries with X-ray emission due to the presence of strong stellar winds (*e.g.*, the O-type stars NGC3603 A1, MY Ser), but most of eclipsing binaries have spectral type G–K, so their X-ray emission is related to the coronal activity. Changes in the phased light curve resulting from the star-spots may influence the distinction between a detached binary with well separated, almost spherical, components and an eclipsing binary with tidally deformed stars. The star HD 184415 (193504-1833.9) with a period of 45.6 d is the longest period eclipsing binary in our catalog, but the eclipses are shallow and probably masked sometimes by star spots.

The periods of detached eclipsing binaries in our sample are between 0.37069 d (ASAS 210445-3525.9) and 43.5 d (ASAS 065114+0754.1). Among detached eclipsing binaries there are two very young stars, as suggests their spectrum and strong lithium line: TYC 8283-264-1 (ASAS 144135-4700.6, orbital period 2.0171 d) and TYC 7310-503-1 (ASAS 145837-3540.5, orbital period 2.09789 d). The second of these stars has been the subject of the recent study by Hebb *et al.* (2011).

The distinction between contact and near contact binaries based on photometry is often unreliable, so our classification is preliminary in this respect and needs to be refined *via* modeling and spectroscopic observations. We are also aware that some stars we consider as contact binaries or eclipsing binaries with deformed components (especially with low amplitude brightness variations) may be in fact variable due to the presence of spots.

Among stars classified as contact binaries there are three outstanding objects with similar properties. These are red stars ($V - I$ color in the range 1.6–1.8 mag) with periods close to one day (ASAS 122456-4854.4, $P = 1.1015$ d, $A_I = 0.16$ mag, $A_V = 0.22$ mag; ASAS 134124-5205.3, $P = 1.35808$ d, $A_I = 0.08$ mag, $A_V = 0.10$ mag; ASAS 162341-3306.2, $P = 0.99498$ d, $A_I = 0.28$ mag), and high X-ray activity with $\log(R_X)$ close to -3 . It is possible that these stars are single fast rotating late K or early M-type dwarfs with large stable spots.

If we ignore these three stars, the periods of the other contact binaries from our list range from 0.21781 d (ASAS 083127+1952.9, subject to the recent study by Ruciński and Pribulla 2008) up to 0.68145 d (DO Cha or ASAS 090744-8219.4).

As ellipsoidal variable stars we classified stars with regular brightness changes, which do not fit to the period–color relation (Eggen 1967) for classical contact binaries. The tidal deformation of a larger component may result in brightness

changes up to 0.2 mag as in the case of AE Aqr (ASAS 204009-0052.2) where the presence of the white dwarf is responsible for the deformation of the main sequence star.

Data found in the literature indicate that 263 non eclipsing stars have spectroscopic companions (there are also 40 stars with probable spectroscopic companions). For 201 stars available data indicate constant radial velocity so we consider these stars as single.

Most of eclipsing stars included in our catalog are in close binary systems, so the rotation of both components should be synchronized or almost synchronized with the orbital period. In the subsequent study of the relation between activity and rotation we will include the eclipsing binaries with the X-ray emission of coronal origin.

4.6. Stars with Miscellaneous Variability Classification

Five stars in our list are classified as miscellaneous variable stars. TYC 8577-1672-1 (ASAS 85008-5745.8) is a blend of a G-type star with an M5III star. Periodicity of 52.5 d is pronounced only in the *I*-band where M-type star should dominate. KP Aqr (ASAS 220945-1353.7, spectral type M2III) with a period of about 22 d may be an example of OSARG type star (Soszyński *et al.* 2011) *i.e.*, the red giant with pulsations supported by convection. The T Tau type star TYC 6793-819-1 (161410-2305.6) presents a luminosity changes with variable amplitude and period of 35.8 d. Its projected rotation velocity (27.5 km/s, T06), implies $R \sin i$ of $19 R_{\odot}$, too large for a K2IV star.

Two other stars are cataclysmic variables presenting at the time of ASAS observations large brightness dispersion and the seasonal modulation of the mean brightness with a period of 10 d (V341 Ara) and 17 d (IX Vel).

Variability of V341 Ara has already been reported many times. The star was initially classified as a type II Cepheid with a period of 11.8 d. Berdnikov and Szabados (1998) found the period of 14.11 d, and *V* amplitude of about 0.5 mag, whereas the period found in the Hipparcos photometry (Perryman *et al.* 1997) was $P = 10.92$ d. V341 Ara has a blue color ($V - I = 0.18$ mag) and O-type spectral classification, so it is probably a nova like variable star. During ASAS observations (seasons 2000–2008) large scatter is present with the amplitude of about 0.5 mag in the *I*- and *V*-bands and we obtain clear periodicity only for the last season of the *V* data. This periodic signal is strong, but the large residua remain (Fig. 8).

IX Vel (ASAS 081519-4913.2) is a well studied nova like cataclysmic variable star with the orbital period of $P_{\text{orb}} = 0.193929$ d. White dwarf has a mass about $0.8 M_{\odot}$ and effective temperature of about 60 000 K. Secondary component fills its Roche lobe and its mass is about $0.5 M_{\odot}$ (Linnell *et al.* 2007). The star has properties similar to V341 Ara. Both have blue color ($V - I \approx 0.2$ mag), similar level of the X-ray activity ($\log(R_x) = -3.15$, although the X-ray spectrum of V341 Ara is harder) and the large scatter in the observed brightness (both in the *I*- and *V*-

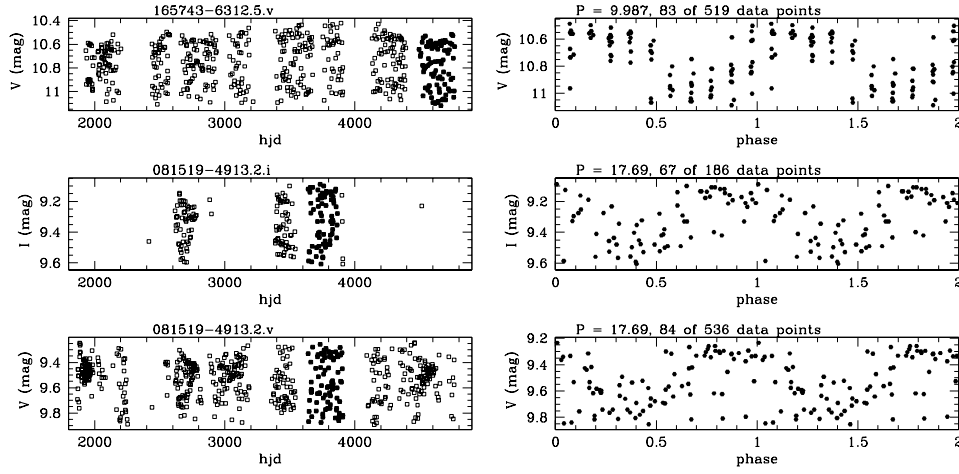


Fig. 8. Photometric data for two cataclysmic binaries V341 Ara and IX Vel. Photometric data points as a function of $\text{hjd} = \text{HJD} - 2450000$ are presented on the *left side*. Phased light curve of data showing periodic variability is presented on the *right side*. V-band data for V341 Ara is presented in the *upper panels*, I-band and V-band data for IX Vel are presented in the *middle panels* and *lowermost panels*, respectively.

bands). There are observing seasons (see Fig. 8) when the large amplitude scatter in the photometric data (flickering?) is modulated with a period of 10 d (V341 Ara) and 17.7 d (IX Vel).

4.7. Projected Rotational Velocities and Minimal Radii of Stars

We consider the projected rotational velocity as a useful information enabling a distinction between the fast and slow rotating stars in cases when photometric data do not eliminate the aliased periods well separated in the period domain. There are 850 stars in our list with the projected rotational velocity found in the literature.

Histogram of $\log(v \sin i)$ is shown in Fig. 9 (left panel). Most stars have projected equatorial velocities in the range 10–100 km/s. The largest projected rotation velocities (over 200 km/s) have been measured for three, most probably very young, G-type stars. G9 spectral type star V370 Vel (ASAS 084214-5256.1) has the rotation period of $P = 0.223$ d (Patten and Simon 1996) and $v \sin i = 235$ km/s (Marsden *et al.* 2009). HD 175897 (ASAS 190109-5853.5) has the spectral type G5V, pronounced lithium line and $v \sin i = 230$ km/s (T06). For this star we have found rotation period $P = 0.4587$ d indicating that this fast rotating star is still in the pre-main sequence phase ($R \sin i = 2.1 R_{\odot}$). BD-14 5534 (ASAS 194536-1427.9) has similar properties: spectral type G6V, $v \sin i = 206$ km/s (T06), and the rotation period equal to 0.5077 d.

The value of $R \sin i$ as a function of rotational period for stars with measured projected rotational velocity is presented in the right side of Fig. 9. There are some cases where the value of the projected rotational velocity seems to contradict the measured rotational period of the star. For example the star CD-45 14393 (ASAS

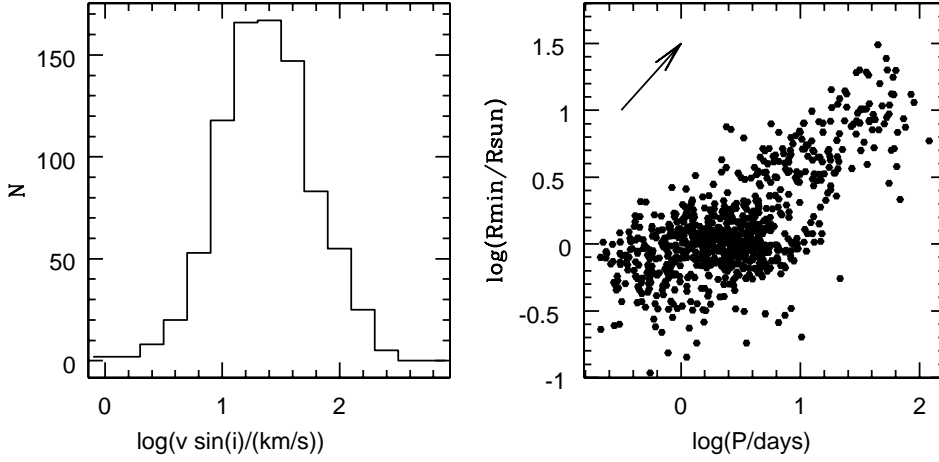


Fig. 9. *Left panel*: histogram presenting number of stars in logarithmic bins of projected rotational velocity (the bin size is 0.2). *Right panel*: inferred minimal radii of stars with the known values of projected rotational velocity plotted as a function of variability period.

213816-4511.5) has the spectral type K3Ve, so its radius should be about $0.7 R_{\odot}$. The projected rotational velocity is 10 km/s (with a formal uncertainty of 2 km/s – T06), whereas the rotational period obtained from photometry seems to be 0.553 d (1.242 d alias is less probable). This indicates $R \sin i = 0.11 R_{\odot}$ ($0.25 R_{\odot}$ for $P = 1.24$ d) which implies a low inclination of the rotation axis to the line of sight (about 10 degrees for $P = 0.553$ d and about 20 degrees for $P = 1.242$ d). Amplitude of the photometric variability is 0.13 mag in V-band which contradicts the low inclination because it implicates very large brightness variations in the equatorial band.

4.8. Stellar Parallaxes and Kinematic Data

Proper motions are listed for 1632 stars from our sample. The star with the largest proper motion, equal to 850 mas/yr, is HD 196998 (ASAS 204142-2219.1). Stars with still larger proper motion were missing in different epochs of ROSAT and ASAS data.

Radial velocity is given for 1092 stars. Histogram representing the number of stars in 4 km/s bins is shown in Fig. 10. Although there are several strong peaks in the histogram, only peaks around 0 km/s can be easily identified with the Lupus–Centaurus–Scorpius association. There are four stars with the radial velocity smaller than -100 km/s, and three with the radial velocity larger than 100 km/s. The most outstanding example is V474 Car (ASAS 090022-6300.1) with radial velocity almost 250 km/s, what makes it a strong candidate for Population II star.

There are 300 stars with full kinematic data *i.e.*, parallax, proper motion, and radial velocity. We plot their U, V, W velocities in Fig. 11. There is a large con-

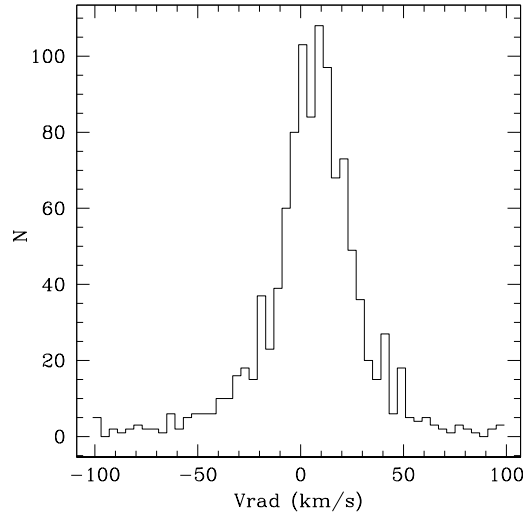


Fig. 10. Histogram of radial velocities for 1092 variable stars based on the data found in literature. The bin size is 4 km/s. Note that part of data is based on a single epoch measurement.

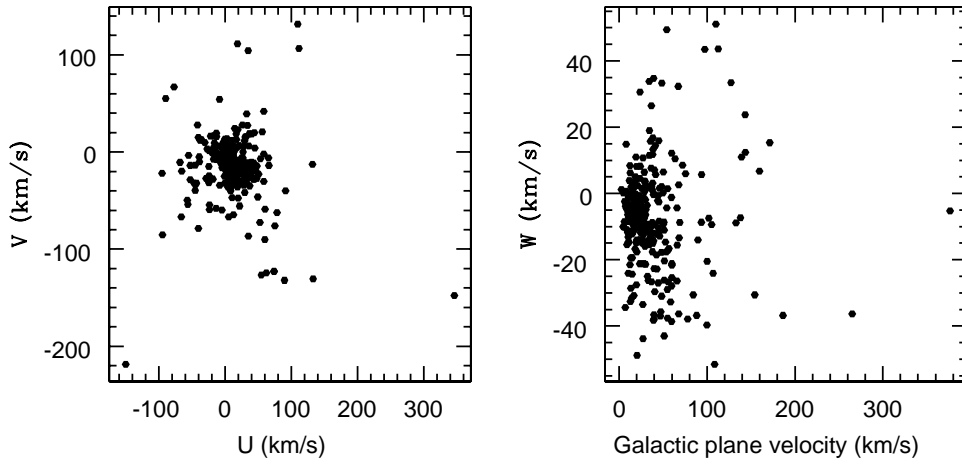


Fig. 11. U and V components of space velocity for stars with given parallax, proper motion, and radial velocity (*left side*). Component of space velocity perpendicular to the Galactic plane (W) vs. velocity in the Galactic plane calculated as $(U^2 + V^2)^{1/2}$ (*right side*).

centration of stars with small velocity relative to the local interstellar medium (young Galactic disk stars), and less numerous stars with the high velocities especially in the Galactic plane. Velocities perpendicular to the Galactic plane are in the range $(-52, +52)$ km/s, but velocities parallel to the Galactic plane are quite large for some stars. Two stars have velocities parallel to Galactic plane significantly larger than others: DR Oct (ASAS 100739-8504.6) has $(U, V, W) = (346, -148, -5)$ km/s, and V474 Car (ASAS 090022-6300.1) has $(U, V, W) = (-150, -219, -36)$ km/s. DR Oct is a SB1 star with a low metal content ($P_{\text{orb}} =$

5.5739 d, $[\text{Fe}/\text{H}] = -2.4$, Ardeberg and Lindgren 1991), and its photometric period is very close to orbital one ($P = 5.574$ d, Cutispoto 1998) and variability typical for the presence of spots. The Population II RS CVn type star V474 Car was a subject of a recent study by Bubar *et al.* (2011). It is also an SB1 star with the orbital period equal to 10.19 d and the ASAS photometric period of 10.26 d.

4.9. X-ray Activity and Objects with the Largest X-ray to Bolometric Luminosity Ratio

The overall period–activity relation for all periodic variable stars in our sample is presented in Fig. 12. The histogram of $\log(R_x)$ is presented in the left panel of Fig. 13.

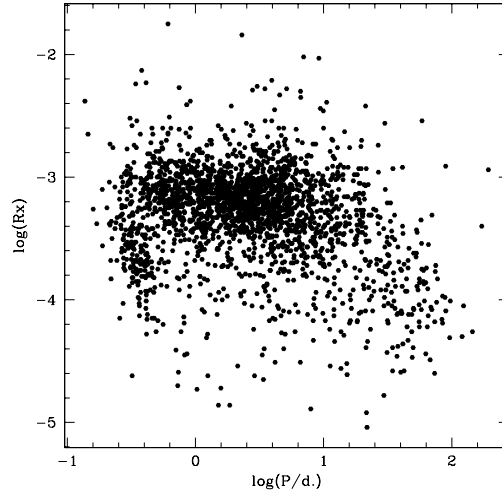


Fig. 12. X-ray to bolometric flux ratio given as a function of variability period for stars listed in the catalog.

The saturation of coronal X-ray emission at the level of $\log(R_x) = -3.0$ is very well established (*e.g.*, Güdel 2004) and it is clearly visible in our data. There are 377 variable objects with $\log(R_x) > -3.0$, only 25 with $\log(R_x) > -2.5$ and 2 with $\log(R_x) > -2.0$. The X-ray emission of two most active stars is not of coronal origin but it is related to the presence of white dwarfs (WD). BV Cen is a cataclysmic binary with an accreting WD and TYC 8769-1214-1 has a close (angular distance $0.''2$) young hot WD companion.

Among ten variable stars with the highest R_x four are related to white dwarfs, (BV Cen, TYC 8769-1214-1, AE Aqr, FF Aqr), three are rotationally variable red dwarfs characterized by $V - I > 2$ mag (ASAS designations: 031523-2821.4, 032439-3904.3, 112548-4410.4), one is an eclipsing binary (RS CVn type star ASAS 080721-1103.6), one is a pre-main sequence star BO Mic (“Speedy Microscopium”), and one (ASAS 121616-5055.3) is a blend of two stars of similar brightness.

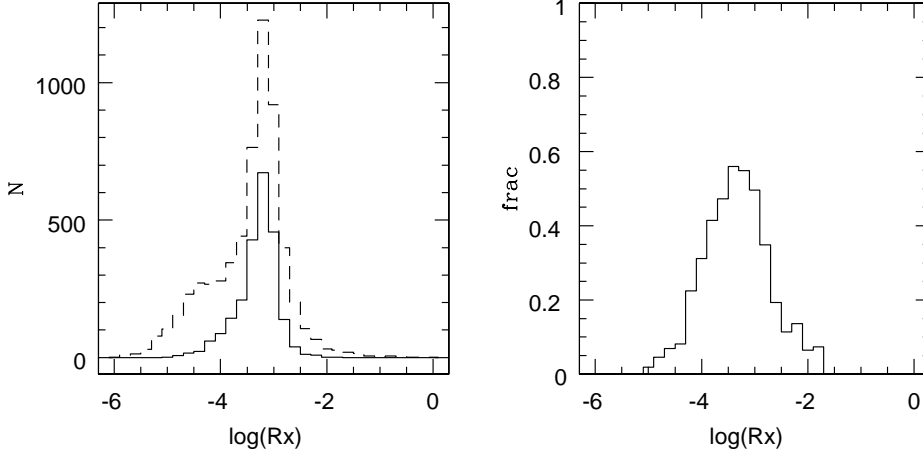


Fig. 13. *Left panel:* number of stars in $\log(R_x)$ bins equal to 0.25. A solid line indicates 2302 periodic variable stars and a dotted line indicates 6028 stars we investigated for periodic luminosity changes. *Right panel:* fraction of variable stars relative to all investigated stars as a function of X-ray activity expressed as $\log(R_x)$.

We are aware that formula derived for X-ray coronal emission may be not adequate for calculation of the X-ray flux and R_x for other type sources like accreting or thermally emitting white dwarfs or wind colliding binaries. Very high X-ray to bolometric luminosity ratio for some M-type dwarfs may be related to flares.

The detailed study of activity–rotation relation for various classes of coronally active stars will be given in the forthcoming papers.

4.10. Fraction of Variable Stars

We were surprised by high fraction of variable stars in our study: 2302 out of 6028 investigated.

Rotational variability of stars is tied to their coronal activity. Most of stars we analyzed for variability have $\log(R_x)$ in the range $(-4, -3)$ and almost 50% of stars in this activity range are variable (see Fig. 13). Activity of $\log(R_x) > -2$ is too high to be of coronal origin so we do not expect variability due to spots. In addition, objects with the highest X-ray to bolometric luminosity ratio are relatively faint, so their photometry is less precise. Lower activity on the other hand is related to the lower magnetic field filling factor, smaller star-spots and weaker variability.

The fraction of the detected variable stars depends to some degree on stellar declination due to the number of available observations. The mean number of observations in the V-band decreases gradually between the declination -75° and 25° from 800 to about 250 measurements per star. The mean number of observations per star in the I-band is roughly constant at the level of 250 measurements per star between -60° and 20° but it drops significantly for declinations greater than 20° . The fraction of stars we found as variable drops from about 45% for declinations smaller than -40° to 25% for declinations larger than 20° .

4.11. Comparison with Earlier Studies

Our variable star list includes many objects known to be variable and included in many previous studies and catalogs. For example we have 58 stars common with Hipparcos survey (KE2002), 76 with SuperWASP variable star study (N07), 731 with ASAS Catalog of Variable Stars (ACVS). Altogether we list 1001 stars with already known photometric or orbital periods, although in many cases our periods are different (mostly due to aliases or a choice of different harmonics).

A brief comparison of our results with N07 was given in the Section 2.1, so here we shortly compare our results with KS2007, KE2002 and ACVS.

Comparison to Kiraga and Stepień (2007)

Our detection threshold in the present study was limited to the cases when AoV statistics for some part of data was larger than 10, so it was more restrictive than in our previous study of M dwarfs where it was set to 8. We analyzed 26 of 31 stars listed as variable in KS2007 and found 18 of them to be variable. For 12 stars, periods listed in the present catalog and periods of KS2007 are similar.

In six cases we list different periods (aliases of the periods given by KS2007), but in three cases we decided to include the periods given by KS2007 to the list of possible aliases.

Comparison with Koen and Eyer (2002)

We calculated AoV statistics for 110 objects present in the KE2002 catalog and 58 are included in our list. We obtained similar periods in 29 cases (50 %). In 10 cases different periods cannot be attributed to aliases or different harmonics.

Comparison with ACVS (ASAS Catalogue of Variable Stars)

We computed AoV statistics for 809 stars coincident with ACVS entries and 731 were included into our final list. Periods of 518 stars are similar, for 92 stars differ by a factor of two, and for 105 they are aliases. For 16 stars the differences are of different origin. The main difference between our work and ACVS is in classification of variable stars.

5. Summary and Conclusions

We analyzed bright ($8 < I < 12.5$ mag or $8 < V < 12.5$ mag) sources from the ASAS – South photometric catalog coincident with the sources from the ROSAT All Sky Survey (Voges *et al.* 1999) and found 2302 of 6028 stars to be variable. The majority of stars have $V - I$ colors and spectral classification typical for coronally active stars possessing convective envelopes, but several cataclysmic variable stars and early type binaries are also present.

We have 731 stars common with ASAS Catalog of Variable Stars (ACVS), 76 stars with Norton *et al.* (2007) and 58 stars common with Koen and Eyer (2002). Altogether 993 photometric periods and 8 spectroscopic ones were found in the literature. Aliasing appears to be the main uncertainty of the obtained periods.

Because of the small angular resolution of ASAS cameras (one pixel equals to

14'') we inspected DSS images for possible blended stars. We found 139 companions of comparable brightness and 336 fainter ones. Additional information about 150 close neighbors was found in the literature and catalogs *via* SIMBAD database. There are 1679 variable stars on our list without significant blending.

Many stars are suspected to be of RS CVn type. There are 127 stars classified as detached eclipsing binaries and 220 stars classified as close eclipsing binaries with deformed components. Data found in the literature indicate that 263 stars not classified as eclipsing binaries have close spectroscopic companions (there are also 40 stars with probable spectroscopic companions). For 201 stars available data indicate constant radial velocity so these stars are most probably single.

For many stars we did not find additional information in the literature and our classification based on photometric data should be considered as preliminary only. In many cases it would be necessary to obtain spectroscopic data to confirm or reject the binary nature of stars listed in the present catalog. In the case of stable variability period, amplitude and phase, we considered a star to be binary. We assume that changes of amplitude indicate the presence of star-spots.

We presented several stars with outstanding properties. Some of them have the X-ray emission of non coronal origin. Most new variable stars have small amplitudes, but there are also examples of stars with very large brightness variations. The star ASAS 063656-0521.0 has a particularly large amplitude due to presence of star-spots (up to $\Delta V = 0.8$ mag, Section 4.4).

The present catalog contains data useful for study of activity–rotation relation for several classes of active stars (young stars, main sequence stars, evolved stars, single stars, close binaries), which will be presented in the forthcoming papers.

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